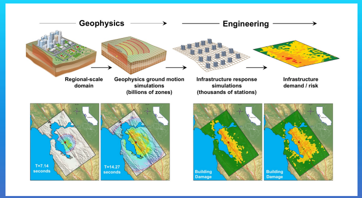

PEER International Pacific Rim Forum
June 16-17, 2021

A Sediment Velocity Model for The Simulation of Basin Amplification Effects in Southern California

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Mechanical and Civil Engineering
CALTECH

June 16 (@USA), 2021

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AN NSF+USGS CENTER

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PEER

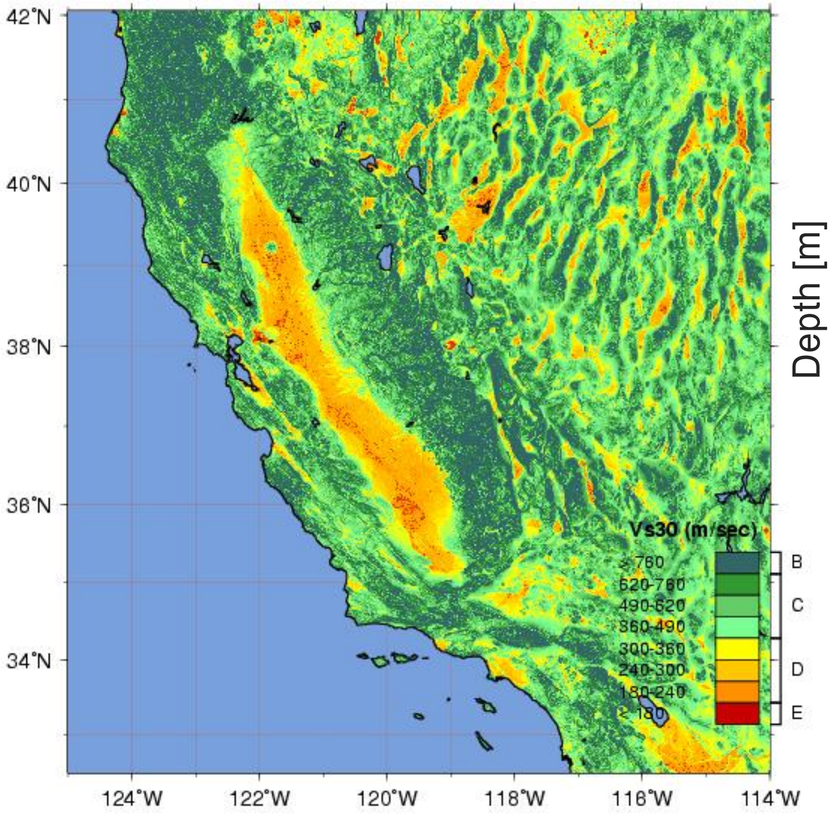
High frequencies can “see" the soil

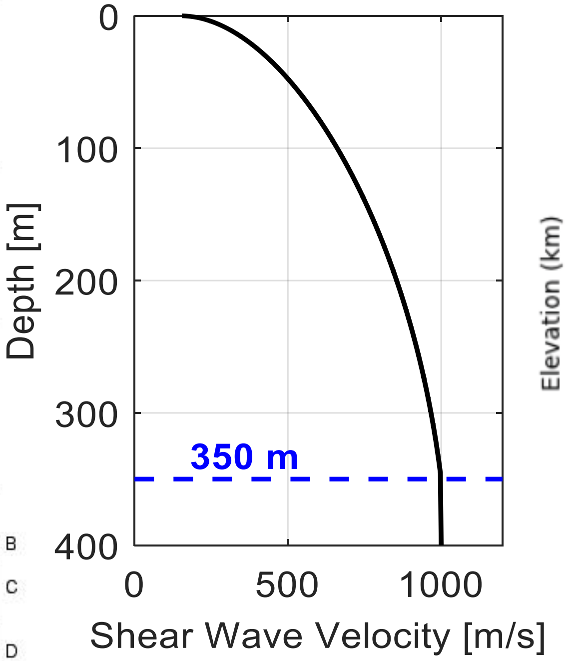
Nonlinear, heterogeneous, anisotropic 3D shallow crust cannot be captured by ‘correction factors’

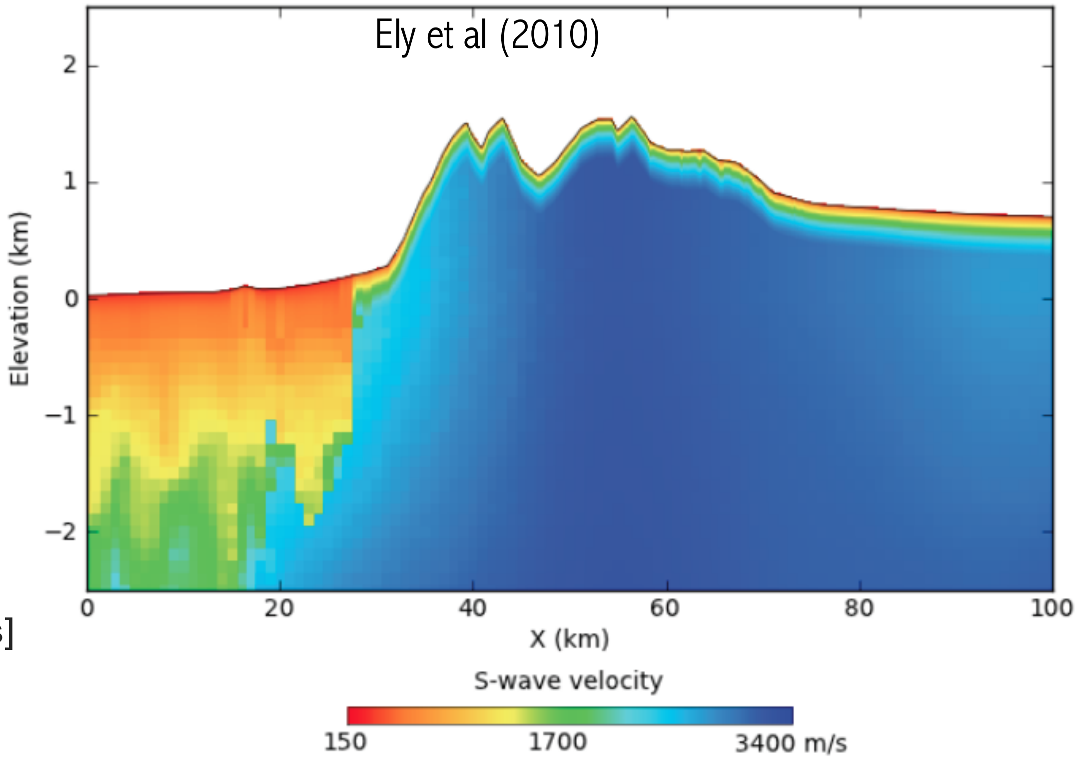
Shallow crust creates conditions / imposes constraints on very large ground motions during very large earthquakes

Shallow crust matters to engineers, and will (significantly) modify the very high frequencies we are trying to propagate

The SCEC Geotechnical Layer (GTL)







Smooth (geometric) Vs function down to 350m

could mask impedance contrasts & alter basin edge geometry:

Deteriorate ground surface predictions compared to CVM-S

Sediment Velocity Model

Idealized model derived from observations (measured Vs profiles)

Function of available physical properties (V_{s30}, z_{1000})

Preserve basin geometry while refining stratigraphy

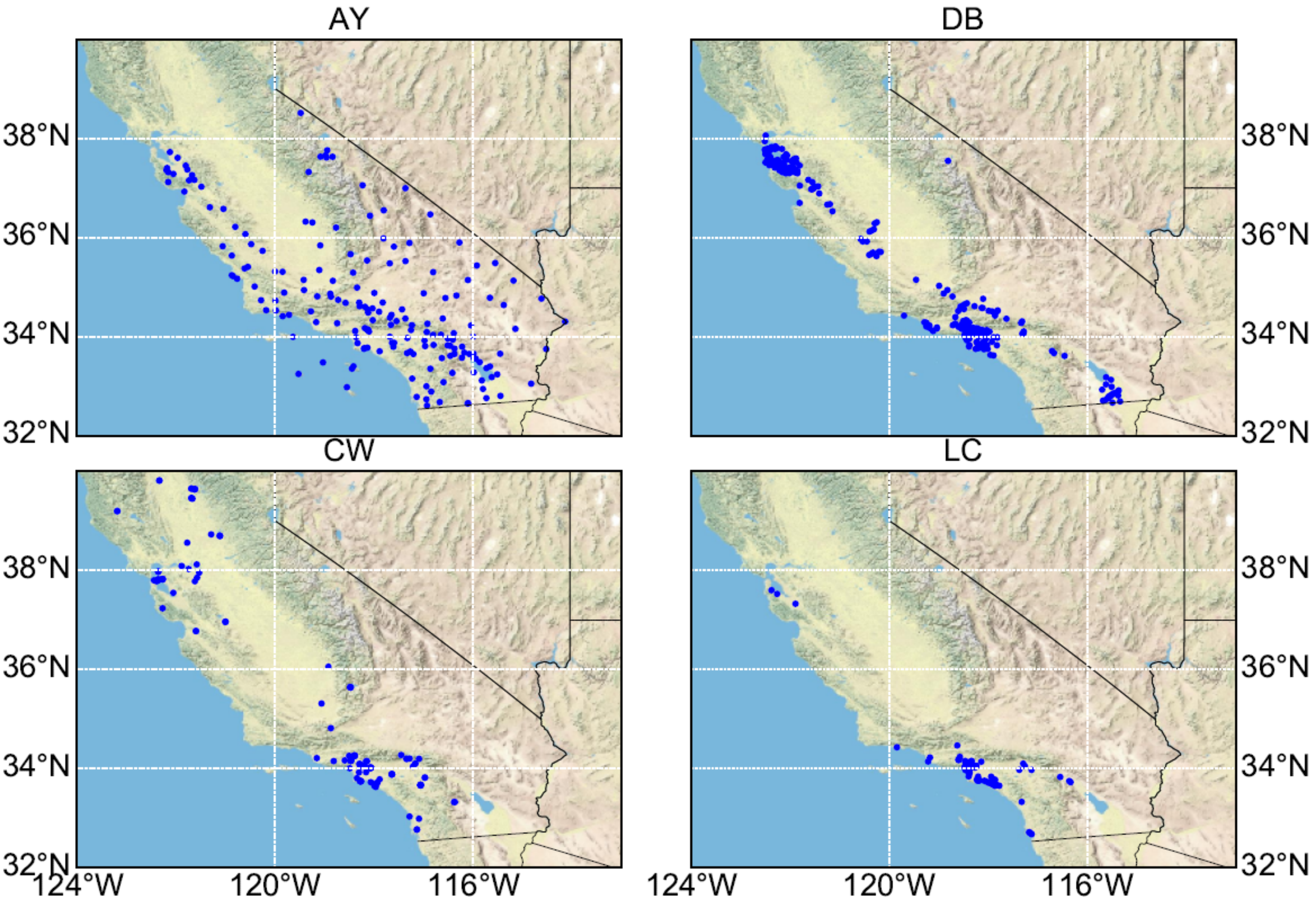
AY: Yong et al. (2013)

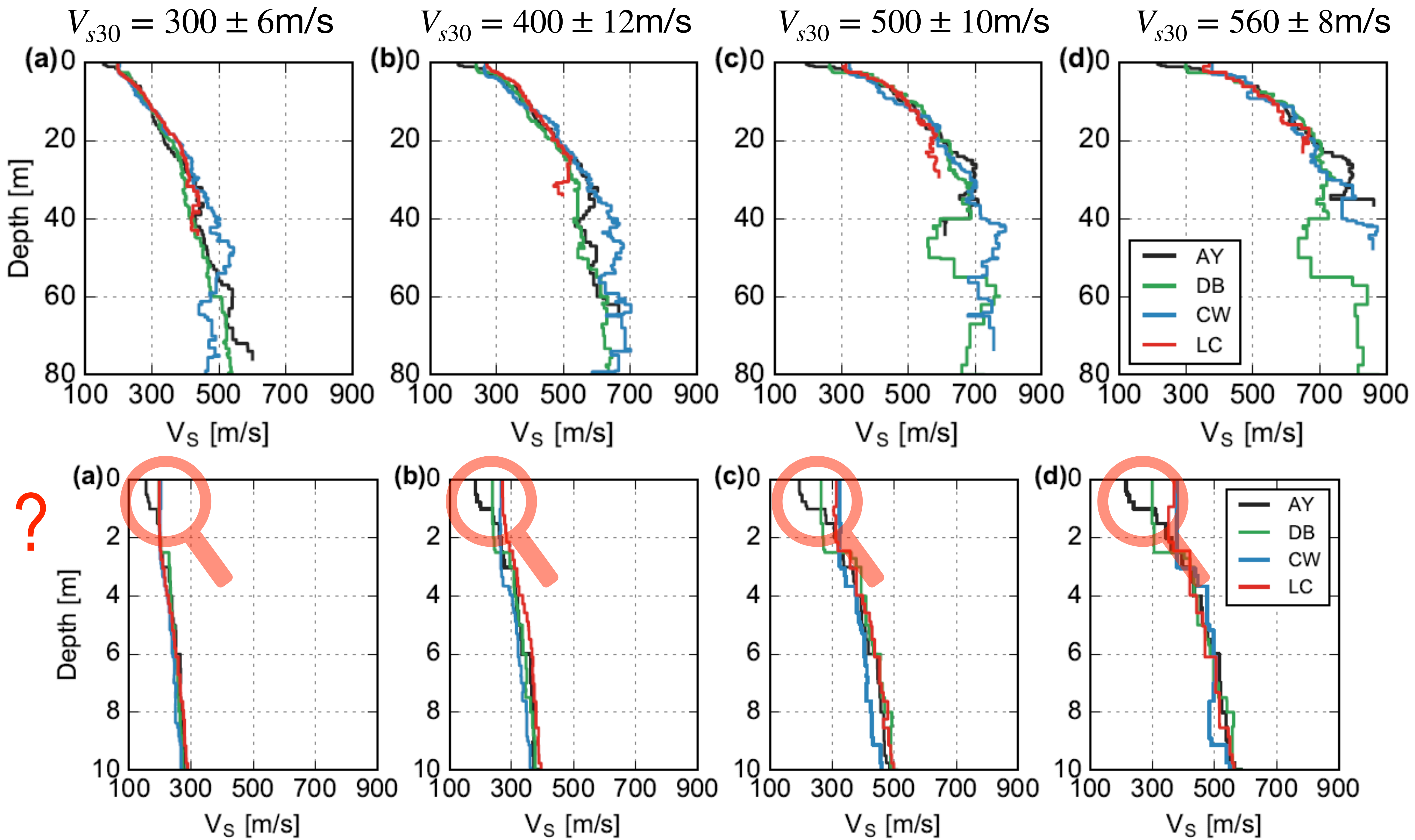
DB: Boore (2003)

CW: Chris Wills with CGS

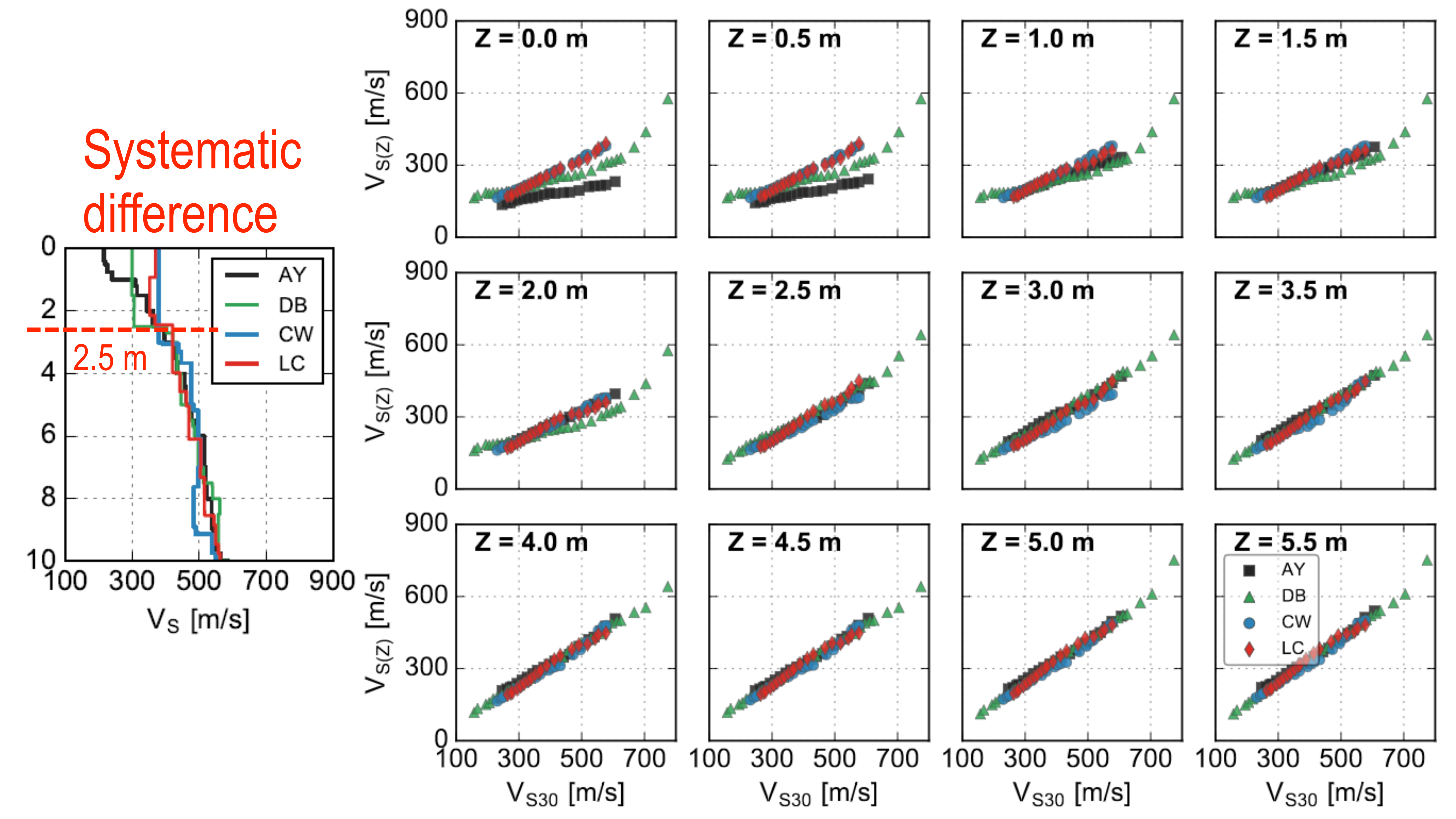
LC: LeRoy Crandall

914 profiles





$V_{s30} = 300 \pm 6$m/s
$V_{s30} = 400 \pm 12$m/s
$V_{s30} = 500 \pm 10$m/s
$V_{s30} = 560 \pm 8$m/s
(a)
(b)
(c)
(d)
Depth [m]
V_S [m/s]
AY
DB
CW
LC
?

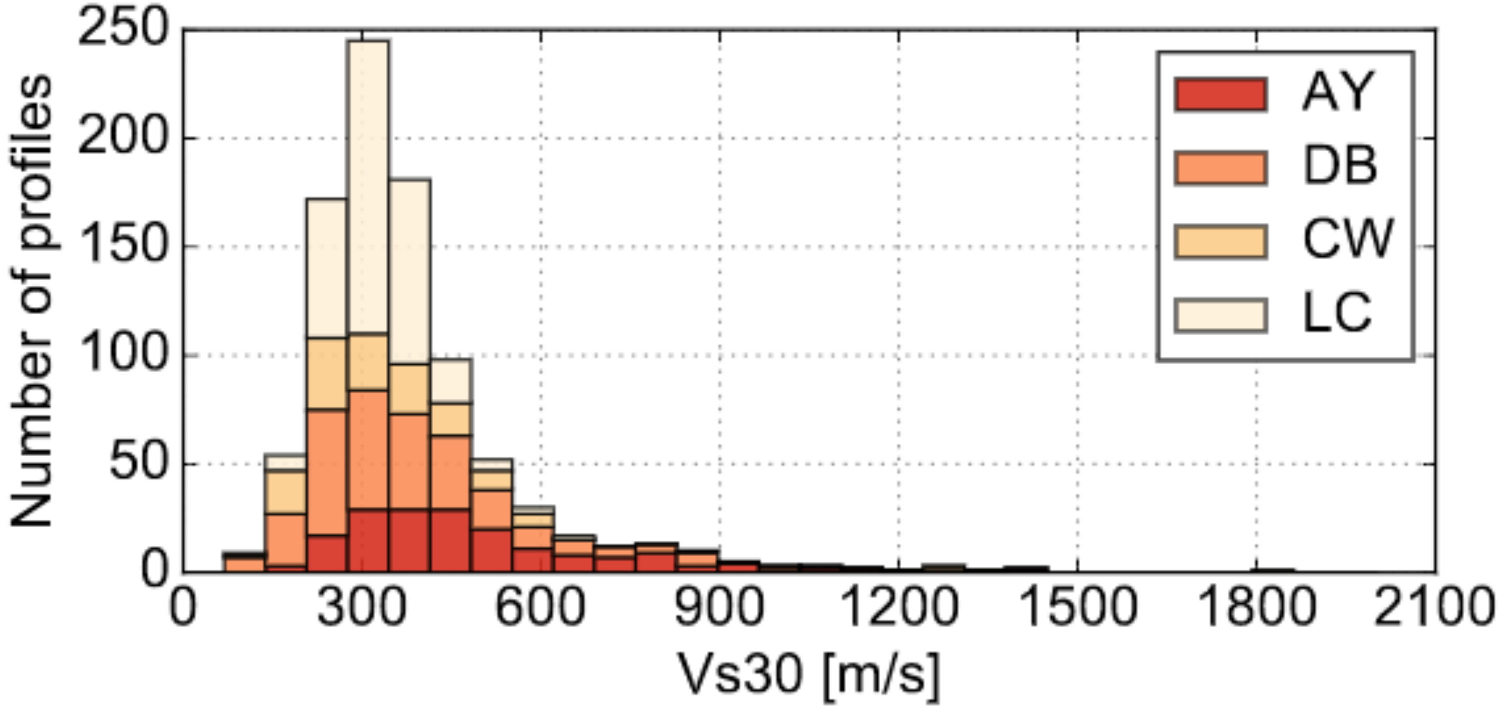


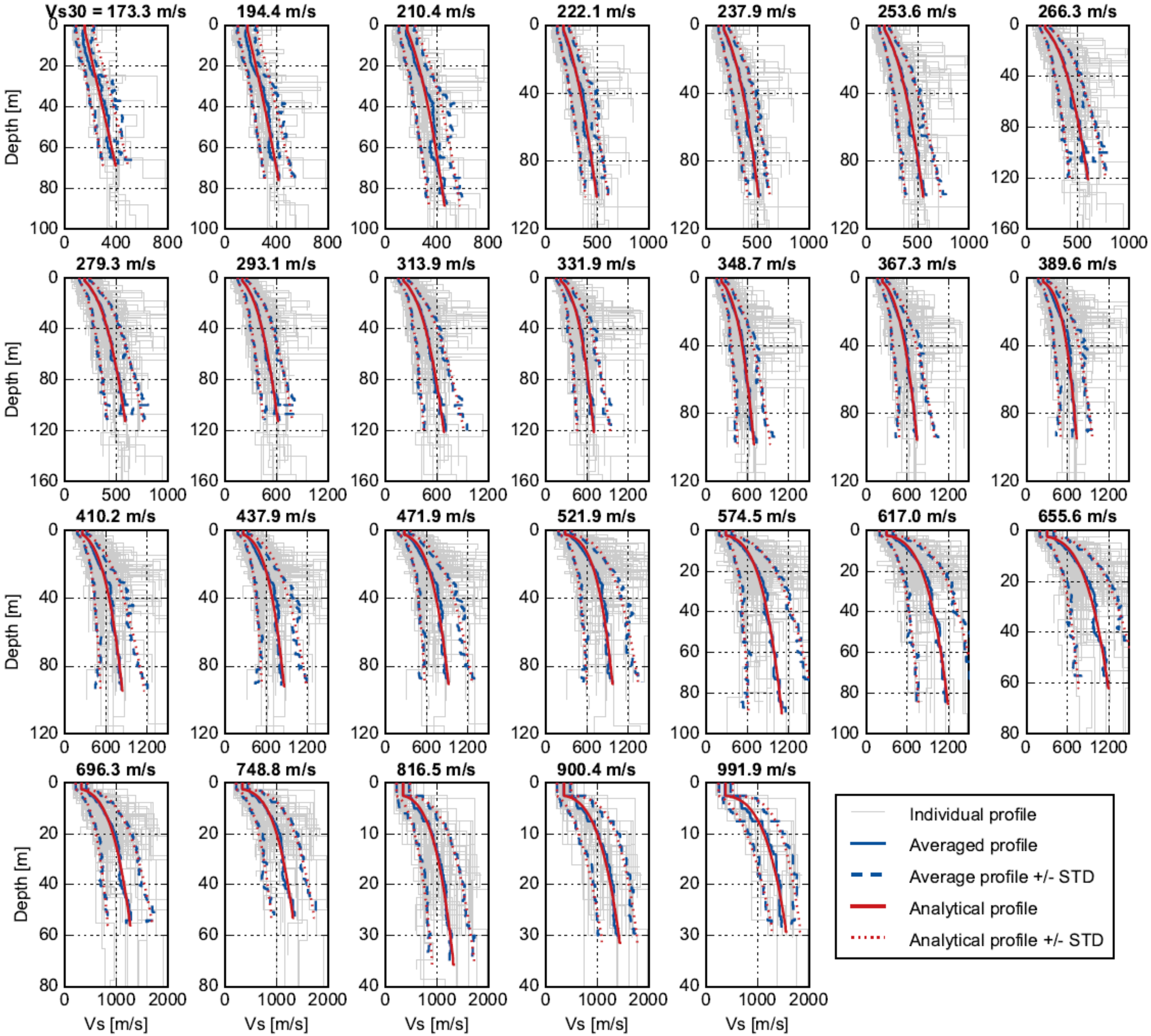
Systematic difference
2.5 m
AY
DB
CW
LC
Vs [m/s]
Z = 0.0 m
Z = 0.5 m
Z = 1.0 m
Z = 1.5 m
Z = 2.0 m
Z = 2.5 m
Z = 3.0 m
Z = 3.5 m
Z = 4.0 m
Z = 4.5 m
Z = 5.0 m
Z = 5.5 m
VS(Z) [m/s]
VS30 [m/s]

SVM model development: Merging 4 datasets in SoCal

$$V_S(z) = \begin{cases} V_{S0} & , 0 \leqslant z < z^* \\ V_{S0}\left(1 + k\left(z - z^*\right)\right)^{1/n} & , z > z^* \end{cases}$$

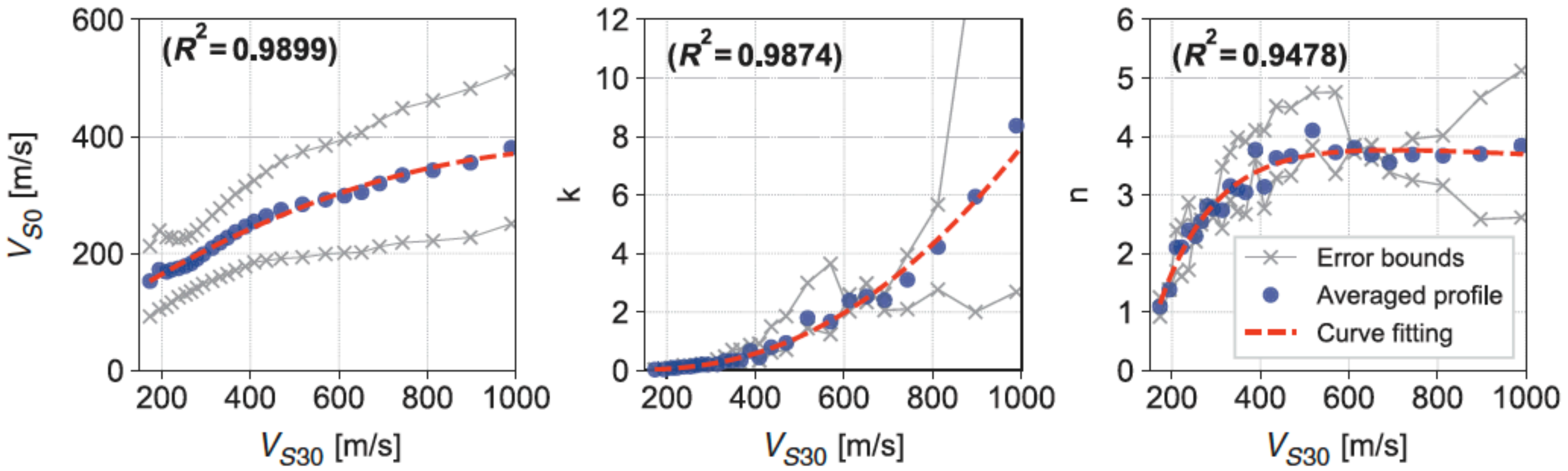
Split profiles in V_{s30} bins, and estimate statistics of profiles within bins




Vs30 = 173.3 m/s
194.4 m/s
210.4 m/s
222.1 m/s
237.9 m/s
253.6 m/s
266.3 m/s
279.3 m/s
293.1 m/s
313.9 m/s
331.9 m/s
348.7 m/s
367.3 m/s
389.6 m/s
410.2 m/s
437.9 m/s
471.9 m/s
521.9 m/s
574.5 m/s
617.0 m/s
655.6 m/s
696.3 m/s
748.8 m/s
816.5 m/s
900.4 m/s
991.9 m/s
Depth [m]
Vs [m/s]
Individual profile
Averaged profile
Average profile +/- STD
Analytical profile
Analytical profile +/- STD

SVM parameters: V_{s0}, k, and n

$$V_S(z) = \begin{cases} V_{S0} & , 0 \leqslant z < z^* \\ V_{S0}\left(1 + k\left(z - z^*\right)\right)^{1/n} & , z > z^* \end{cases}$$

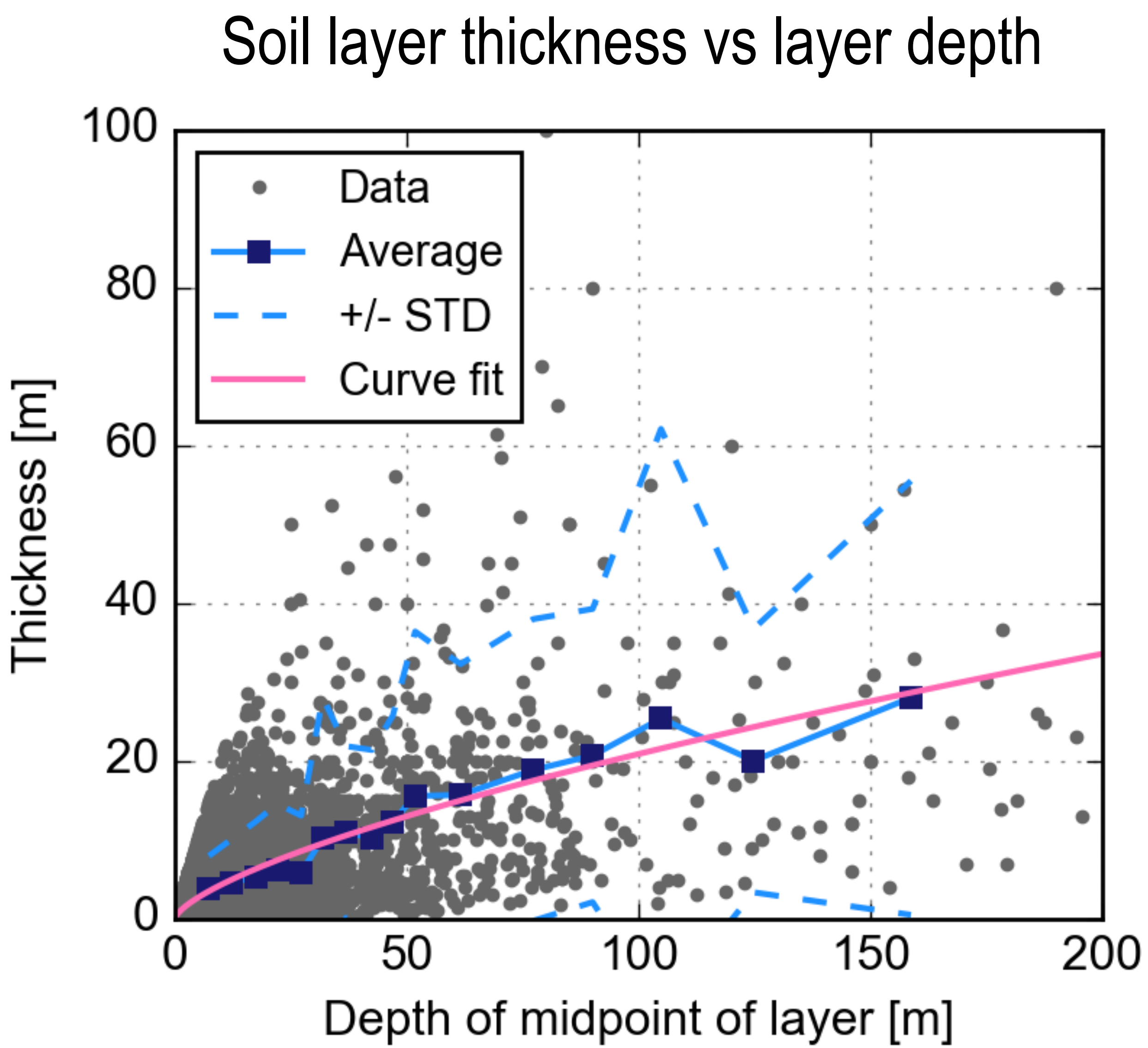


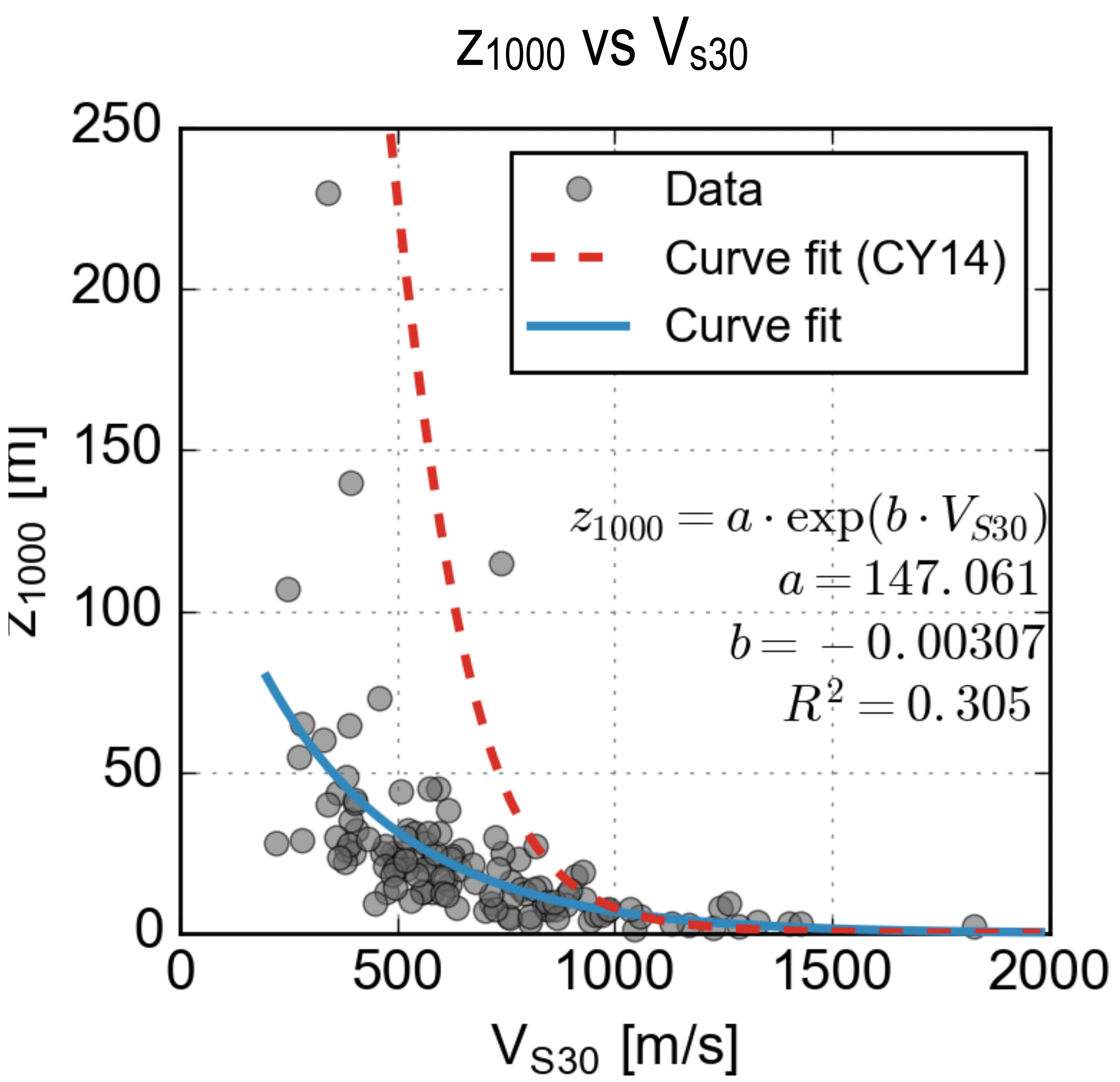
$$V_{S0} = p_1\left(V_{S30}\right)^2 + p_2\left(V_{S30}\right) + p_3$$

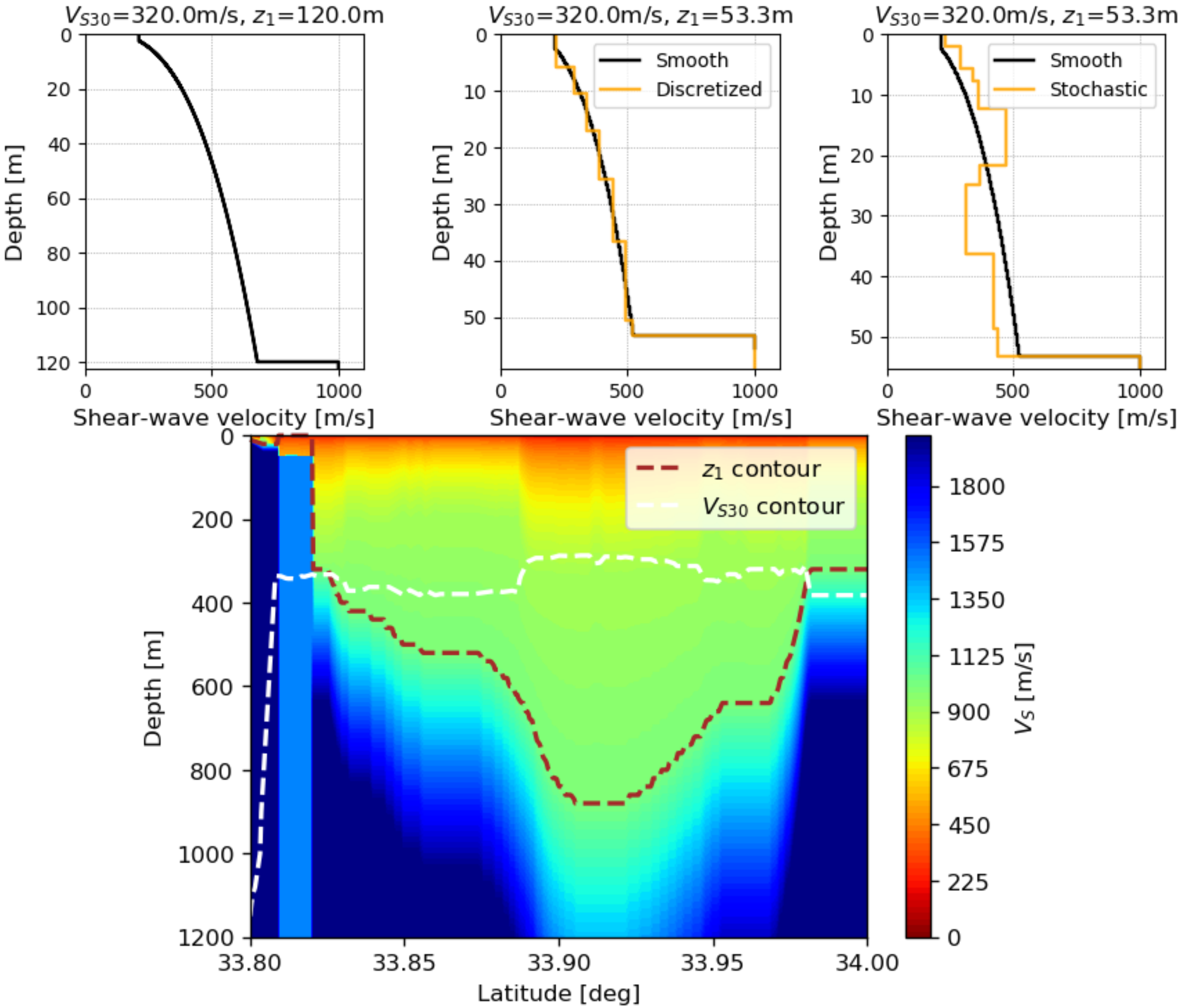
$$k = q_1\left(V_{S30}\right)^{q_2} + q_3$$

$$n = s_1 \exp\left(s_2 V_{S30}\right) + s_3 \exp\left(s_4 V_{S30}\right)$$

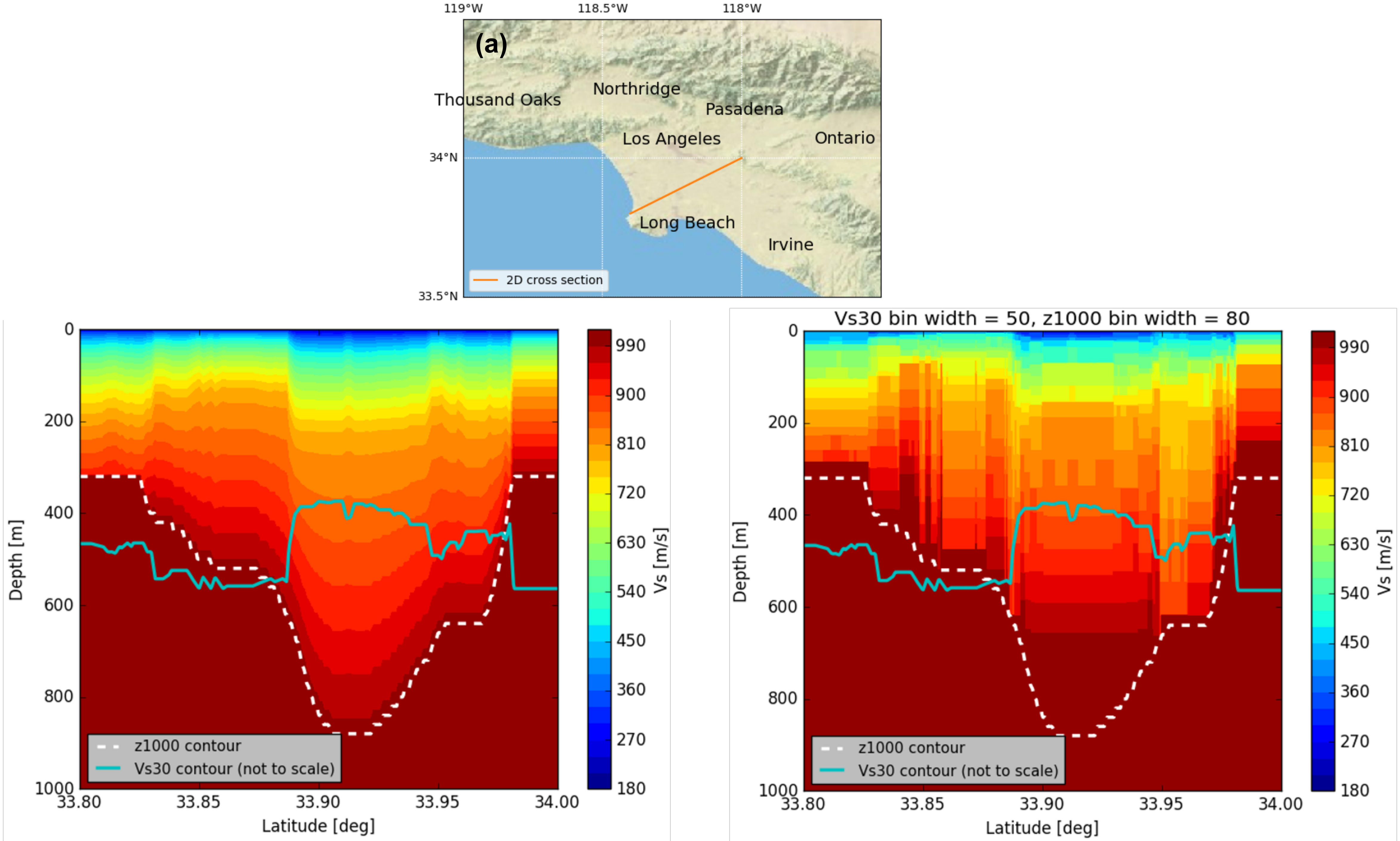
Additional data-driven relationships in SVM







V_{S30}=320.0m/s, z_1=120.0m
V_{S30}=320.0m/s, z_1=53.3m
V_{S30}=320.0m/s, z_1=53.3m
Smooth
Discretized
Smooth
Stochastic
Depth [m]
Shear-wave velocity [m/s]
z_1 contour
V_{S30} contour
Latitude [deg]
V_S [m/s]

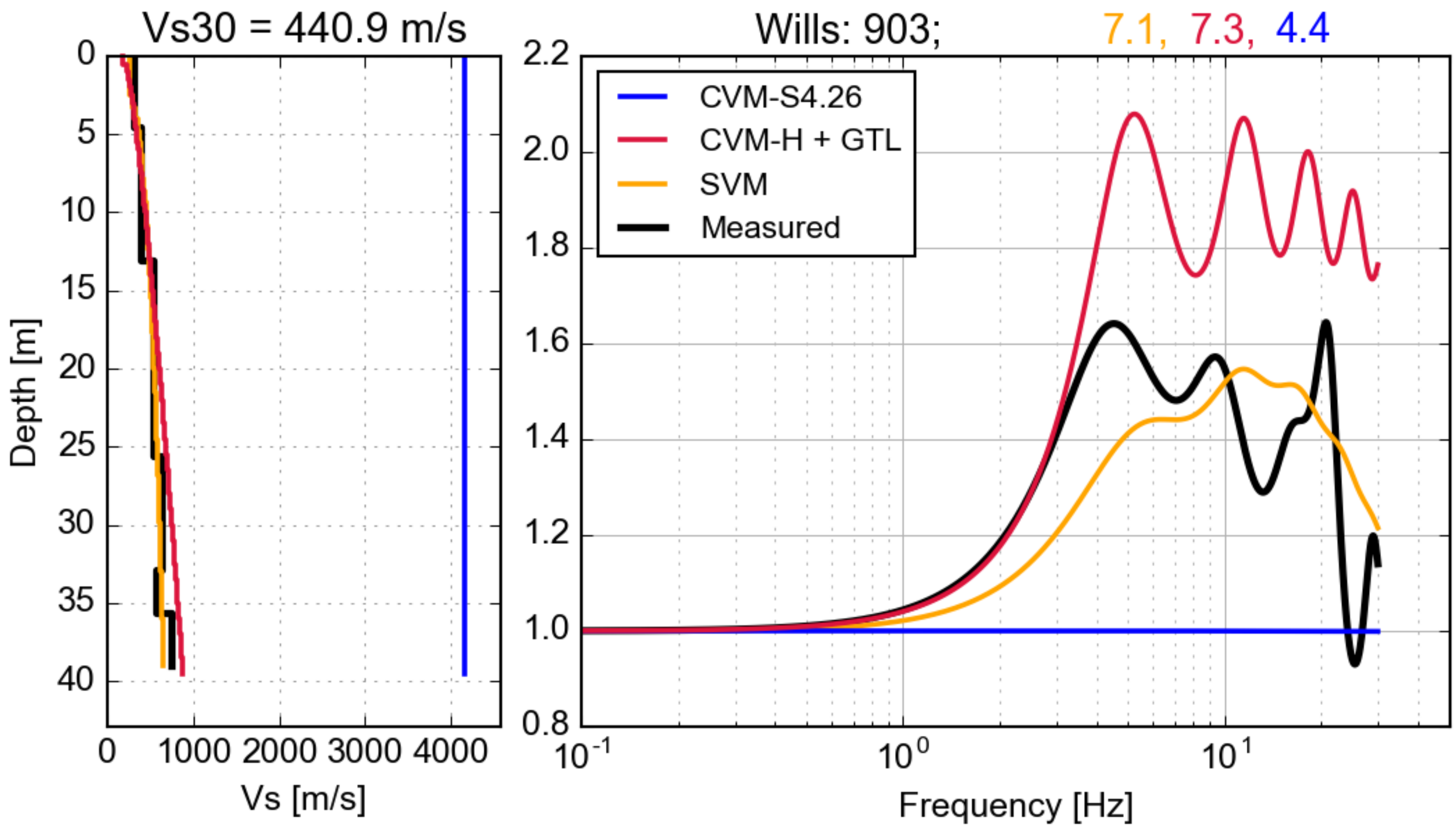

(a)
119°W
118.5°W
118°W
34°N
33.5°N
Thousand Oaks
Northridge
Pasadena
Los Angeles
Ontario
Long Beach
Irvine
2D cross section
Vs30 bin width = 50, z1000 bin width = 80
Depth [m]
Latitude [deg]
Vs [m/s]
z1000 contour
Vs30 contour (not to scale)
0
200
400
600
800
1000
33.80
33.85
33.90
33.95
34.00
180
270
360
450
540
630
720
810
900
990

Validation of 1D profiles and amplification factors

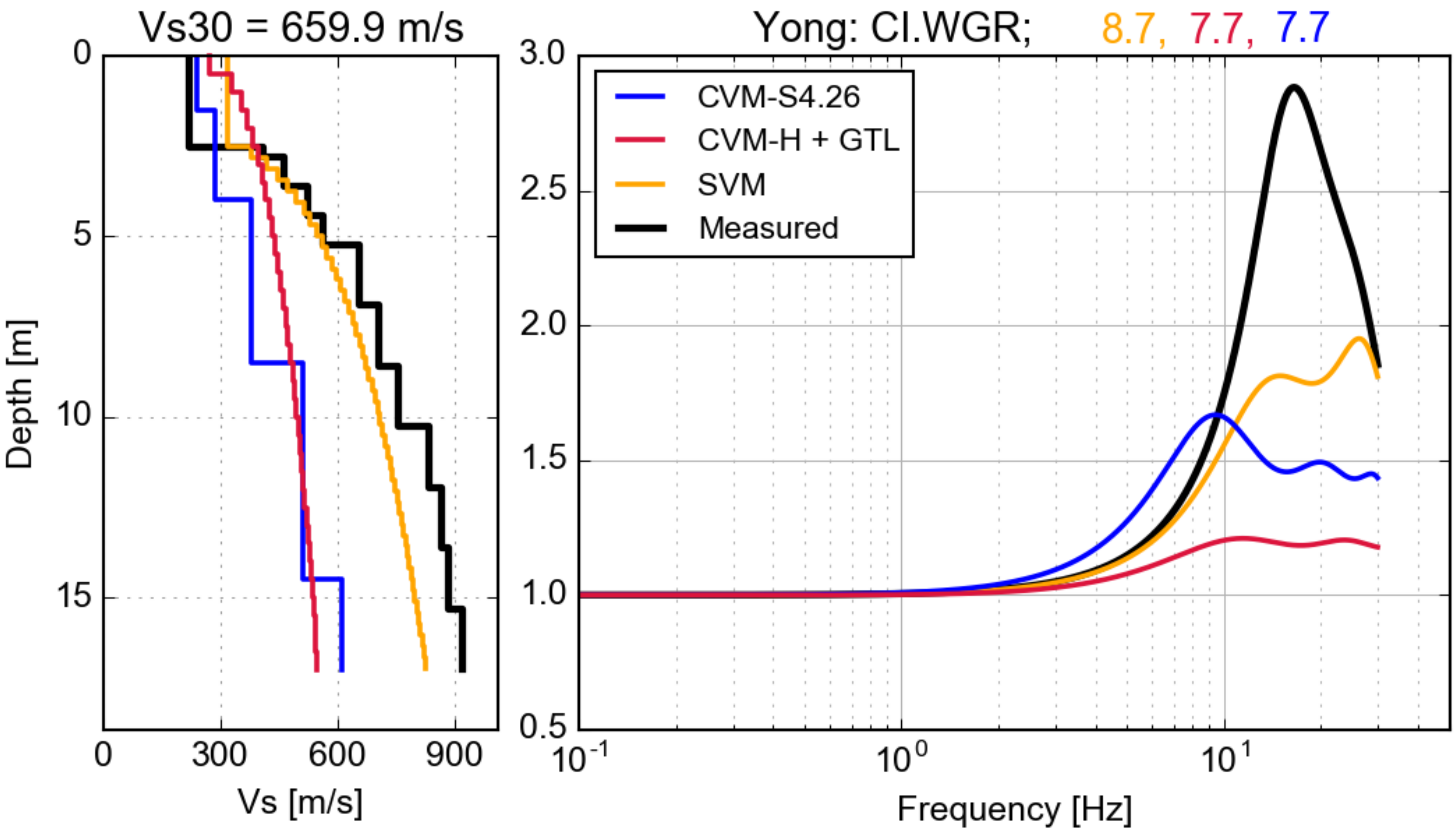
GOFs: Relative error of Vs profile and 1D amplification function

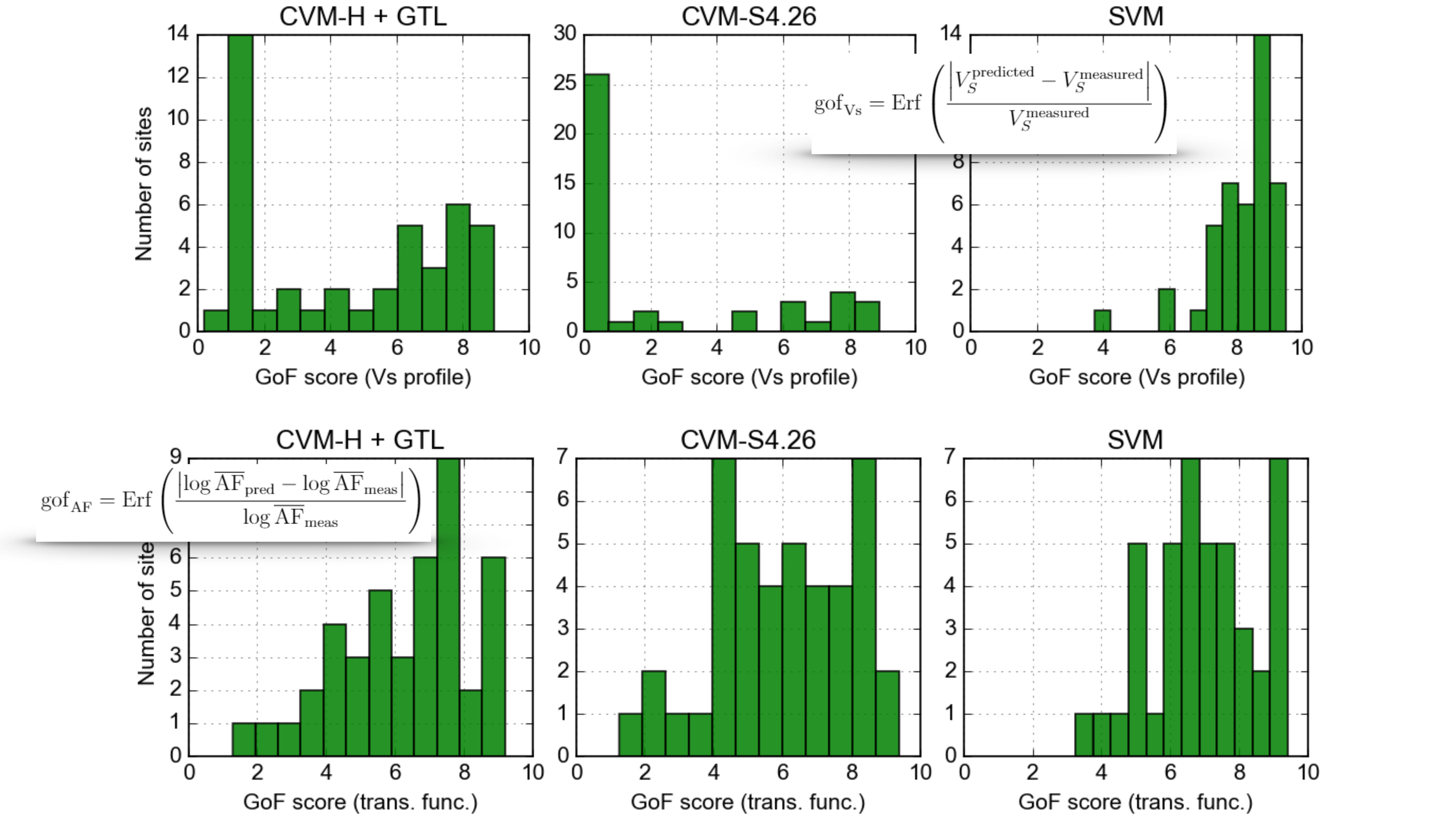
Compare SVM with: CVM-S4.26 and CVM-H with GTL

Validation is performed on a hold-out dataset of 43 profiles (not used in training)



Vs30 = 440.9 m/s
Depth [m]
Vs [m/s]
0
5
10
15
20
25
30
35
40
0
1000
2000
3000
4000
Wills: 903;
7.1,
7.3,
4.4
CVM-S4.26
CVM-H + GTL
SVM
Measured
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
10^{-1}
10^{0}
10^{1}
Frequency [Hz]


Vs30 = 659.9 m/s
0
5
10
15
Depth [m]
0
300
600
900
Vs [m/s]
Yong: CI.WGR; 8.7, 7.7, 7.7
3.0
2.5
2.0
1.5
1.0
0.5
CVM-S4.26
CVM-H + GTL
SVM
Measured
10^{-1}
10^{0}
10^{1}
Frequency [Hz]



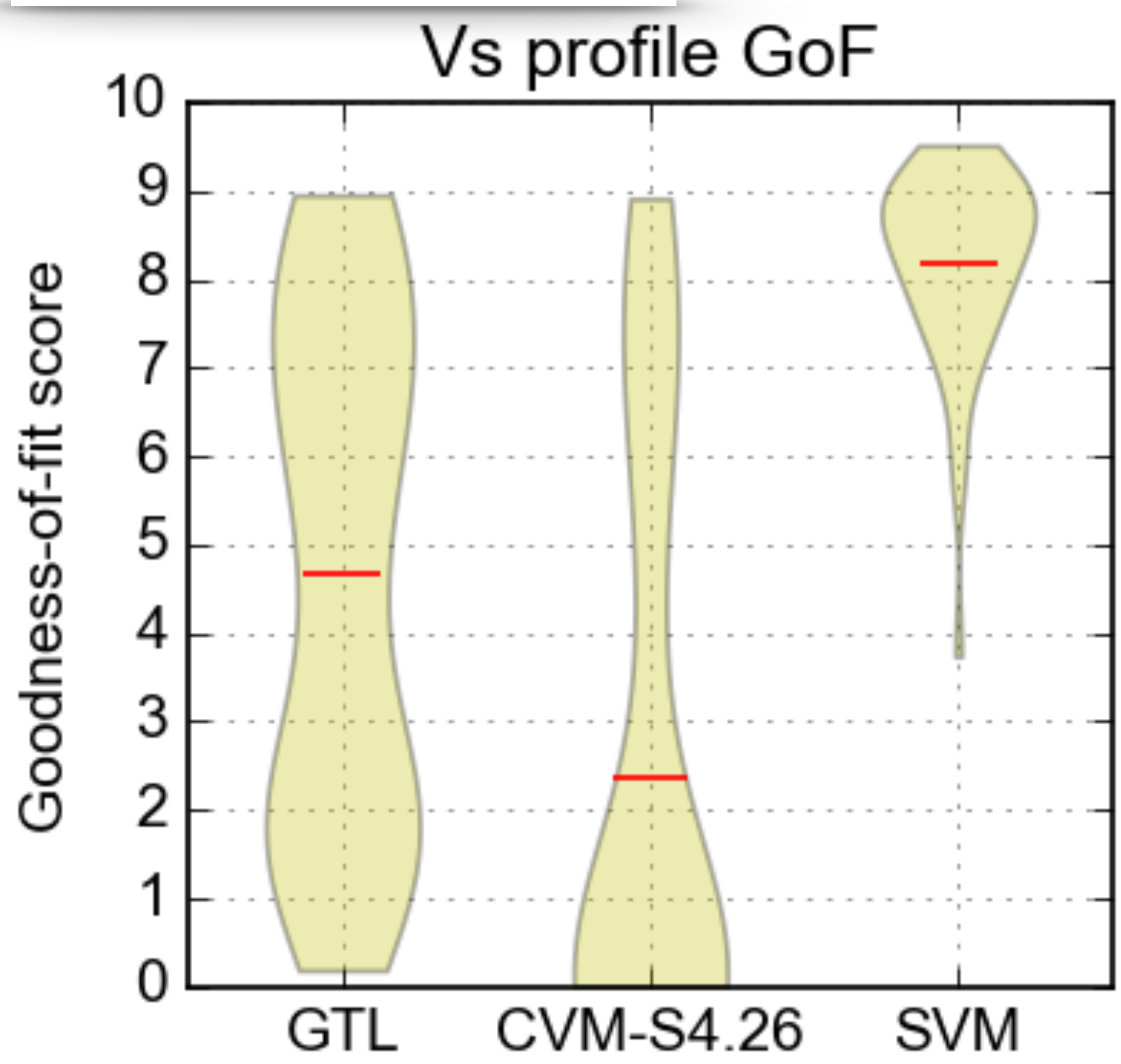
$$\mathrm{gof}_{\mathrm{Vs}} = \mathrm{Erf}\left(\frac{\left|V_S^{\mathrm{predicted}} - V_S^{\mathrm{measured}}\right|}{V_S^{\mathrm{measured}}}\right)$$

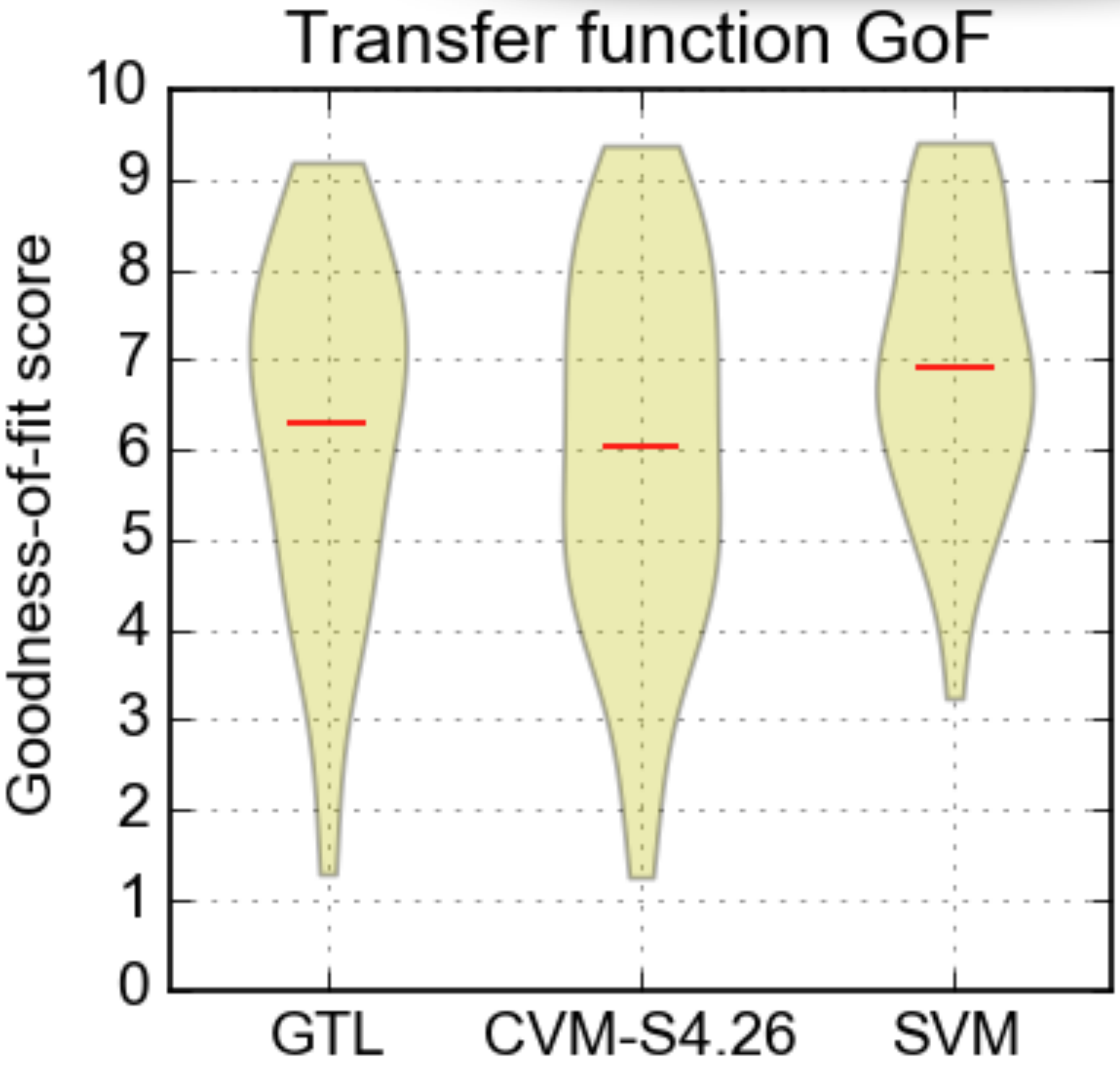
$$\mathrm{gof}_{\mathrm{AF}} = \mathrm{Erf}\left(\frac{\left|\log \overline{\mathrm{AF}}_{\mathrm{pred}} - \log \overline{\mathrm{AF}}_{\mathrm{meas}}\right|}{\log \overline{\mathrm{AF}}_{\mathrm{meas}}}\right)$$

$$\mathrm{gof}_{\mathrm{AF}} = \mathrm{Erf}\left(\frac{\left|\log \overline{\mathrm{AF}}_{\mathrm{pred}} - \log \overline{\mathrm{AF}}_{\mathrm{meas}}\right|}{\log \overline{\mathrm{AF}}_{\mathrm{meas}}}\right)$$

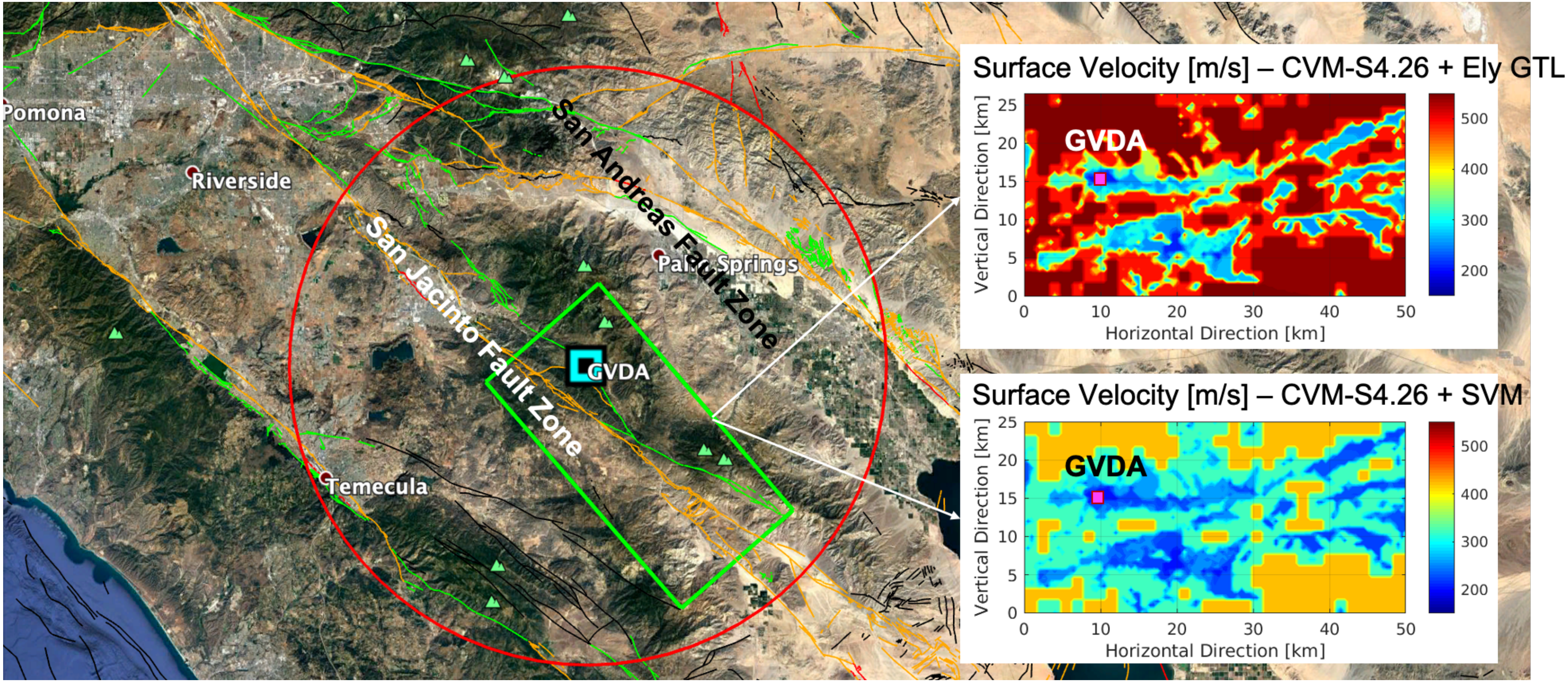
Validation set profiles

$$\mathrm{gof}_{\mathrm{Vs}} = \mathrm{Erf}\left(\frac{\left|V_S^{\mathrm{predicted}} - V_S^{\mathrm{measured}}\right|}{V_S^{\mathrm{measured}}}\right)$$

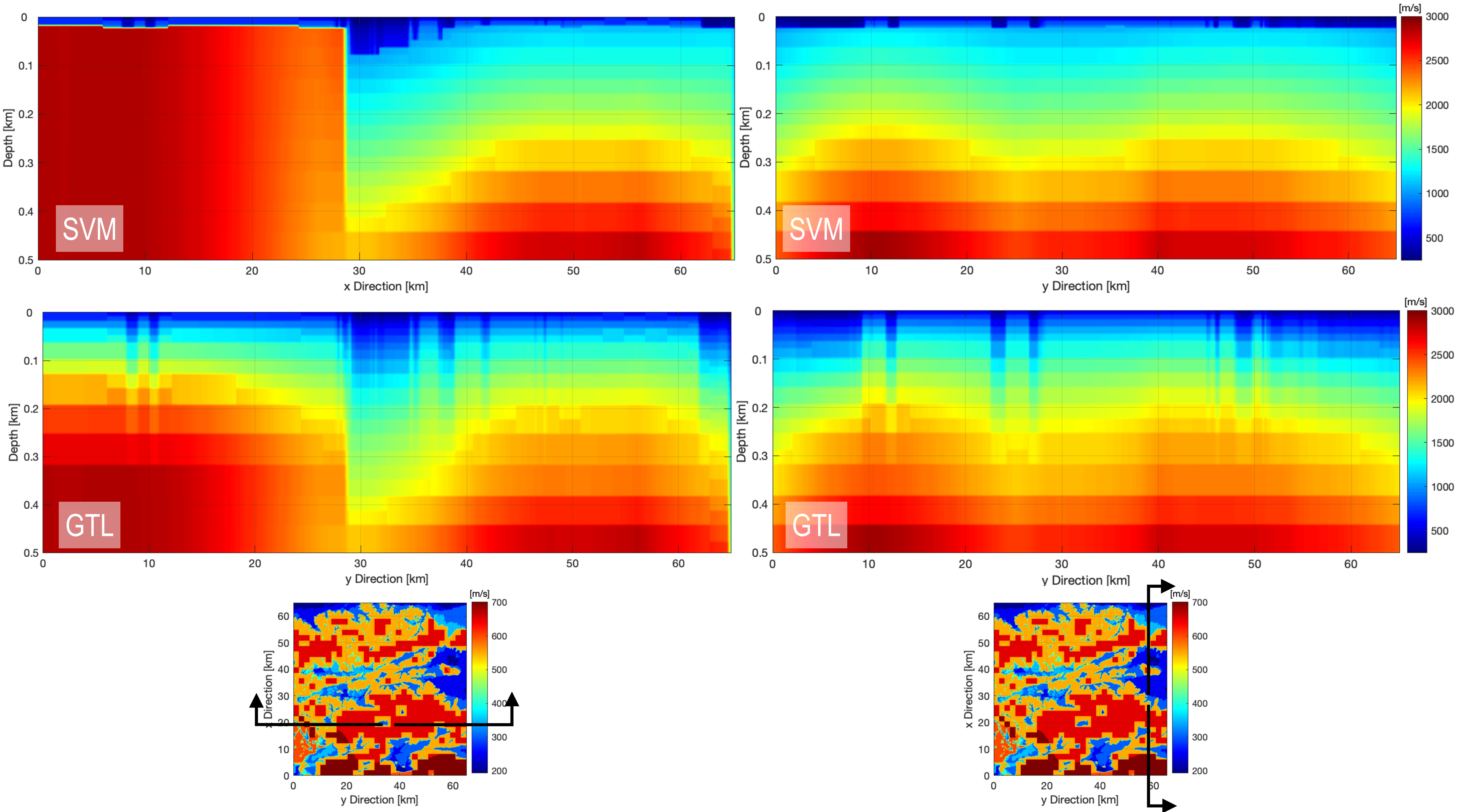




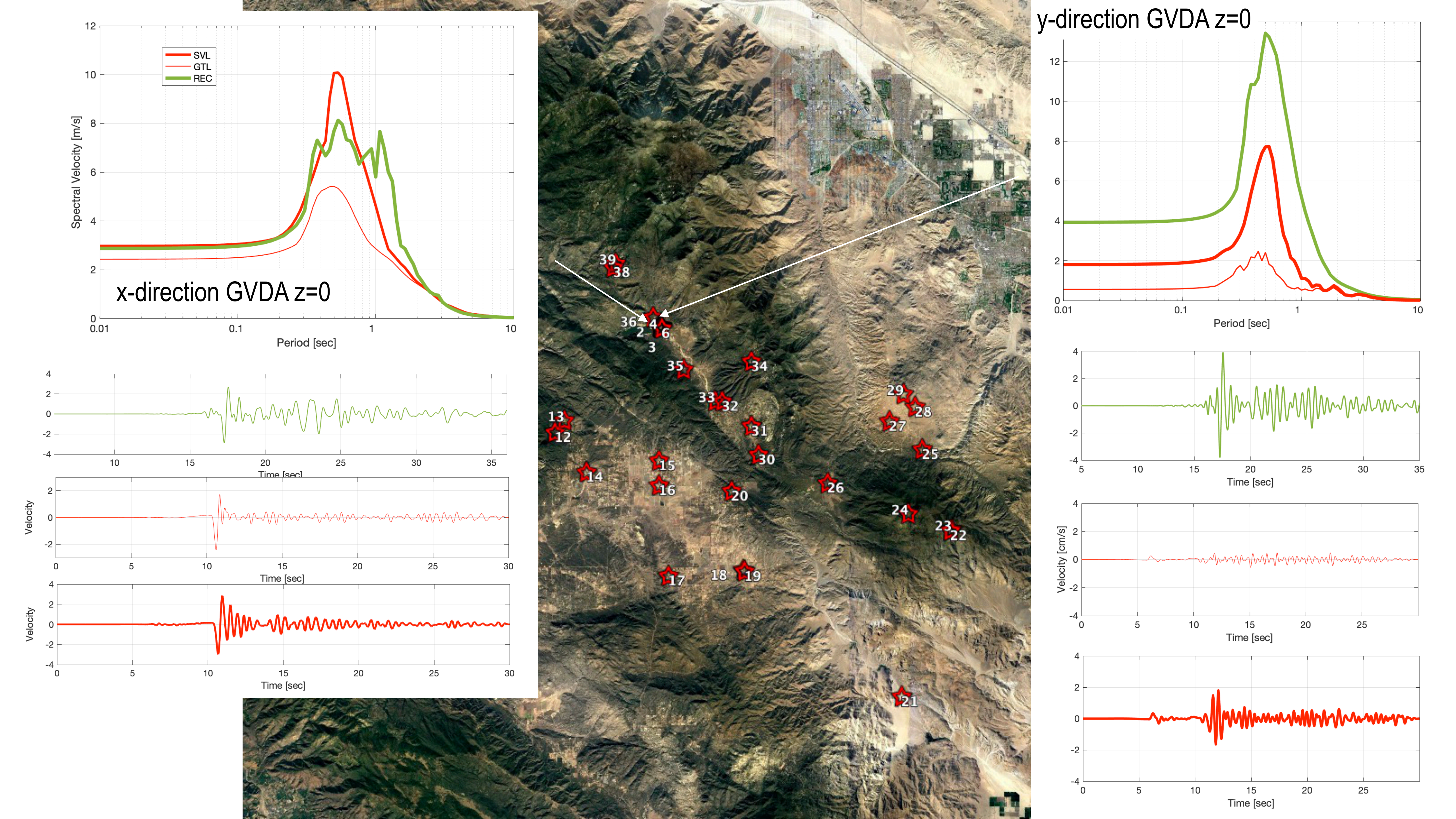
Borego Springs M5.4



in collaboration with UNR (Prof. E. E. Seylabi)



SVM
Depth [km]
x Direction [km]
SVM
y Direction [km]
[m/s]
GTL
y Direction [km]
GTL
y Direction [km]
x Direction [km]


x-direction GVDA z=0
SVL
GTL
REC
Spectral Velocity [m/s]
Period [sec]
Velocity
Time [sec]
y-direction GVDA z=0
Velocity [cm/s]
39
38
36
4
2
6
3
35
34
33
32
31
30
29
28
27
25
26
24
23
22
13
12
14
15
16
20
17
18
19
21

Future work

- Implement at dense array site/DAS site; couple with spatial statistics
- Test for larger region + scenario simulation
- Transfer framework to Northern CA (in collaboration with Elnaz Seylabi)

We need to synthesize higher resolution shallow crust models if we are targeting high frequencies

Check out our Python routines; Jupyter notebooks:

https://github.com/jsh9/PySeismoSoil

Reference:

J. Shi, D. Asimaki (2018) "A Generic Velocity Profile for Basin Sediments in California Conditioned on Vs30." Seismological Research Letters, 89 (4), 1397-1409.

Thank you!

Questions?

email me at domniki@caltech.edu